The e+A focus weeks week 5 discussion: write-up jets & hadronization

Alberto Accardi, Elke Aschenauer,
Markus Diehl, Matt Lamont,
Cyrille Marquet

https://wiki.bnl.gov/eic/index.php/QCD_Matter_under_Extreme_Conditions

Outline/Thoughts on Write-Up

- Published as a volume – editor to be confirmed
- Aim of overall volume to be ~ 400 pages
- Leaves 100 pages/topic if divided equally
- Timescale of individual contributions submitted to co-ordinators is ~ **mid-December** (to be confirmed)
- Write-up will be co-ordinated via the INT wiki page

Outline/Thoughts on Write-Up

- Introduction to e+A programme
  - Written by Accardi, Lamont, Marquet
- Nuclear effects on a log-scale (or Saturation and small-x physics)
- Nuclear effects on a linear-scale (or Nuclear effects across the whole x-Q2 plane)
- Parton propagation and Hadronization
- Connection of e+A to p+A, A+A?
- e+A MC situation
  - generators, radiative corrections, ...
    - Toll, Ullrich, Kowalski, Aschenauer, Cole, Dupré , Gallmeister
- Experimental Considerations for e+A → in a separate chapter
    - Aschenauer, Nadel-Turonski….
- Golden Measurements

Saturation and small-x physics

- Introduction and review of linear and non-linear approaches in QCD
  - DGLAP - state of the art/nPDFs (Rojo?/Salgado...)
  - CGC - state of the art
  - “Bartels”
  - “Pirner”
  - “Kopeliovich”
  - Leading-twist shadowing (a la Guzey/Strikman)

Authors: Lappi
Guzey
Kopeliovich
Bartels
Pirner
Marquet
Rojo?

- Inclusive F_2, F_L
  - Integrated gluon distribution

Authors: Lappi
Accardi
Goncalves

- Exclusive VM, DVCS - G(b)
  - Coherent vs Incoherent
  - J/ψ vs ρ vs φ

Authors: Lappi
Marquet
Kowlaski
Toll
Ullrich
Goncalves

Saturation and small-x physics

- Inclusive diffraction (F_2^D, F_L^D)
  - CGC expectations
  - Leading twist

Authors: Marquet
Guzey

- SIDIS - G(kT)
  - 1 hadron/jet
  - di-hadron/jet
  - light vs heavy flavour

Authors: Xiao
Marquet
Soyez++

- Connection of e+A to A+A
  - Initial conditions
  - Fluctuations

Authors: Horowitz
Gelis

Nuclear effects at larger x, Q^2

- EMC Effect
  - What can be learned at an EIC? (Cloet)
  - Gluon nucear modifications
- PVDIS, A3
- Colour Transparency
  - J/ψ, Charmonium (Kopeliovich)
- nGPDs (Guzey)
- nTMDs (Zhou)

Jets and hadronization

- pre-hadron absorption (Pirner, Gallmeister)
- test of energy loss
  - heavy flavour (Kopeliovich, Potashnikova, Dupre, Horowitz)
    - B vs D
  - light (Dupre, Pirner)
    - π vs η (test of hadronization times)
  - jets (Soyez++)
  - modified DGLAP (Pirner, Majumder)
  - Bose-Einstein Correlations (Gilfoyle)
  - Target fragmentation? (Strikman)
  - Links to A+A… (Horowitz, Accardi…)
- probe of the medium
  - transport coefficients, ... (Majumder)

EIC Science Matrix

Gain/Loss vs. HERA	Primary New Science Deliverables	Basic Measurements	Typical Required Precision	What We Hope Fundamentally To Learn	What we hope to learn with phase I	Alternatives in Absence of EIC	Comments
s ÷ 2.5-4 but Ion Beams up to A~200	$Q_{sat}^2(x,A)$? Gluon distribution						Gain in A more than compensates for loss in s, in terms of reach into gluon saturation regime
Polarized nucleon beams	ΔG(low x) ? Bjorken SR TMD's to probe transverse-momentum-spin correlations						
$\mathcal{L}$ × 100-1000	GPD's to yield transverse spatial maps vs. x_{Bj}						
$\mathcal{L}$ × 100-1000	EW symmetry-violating processes (e→τ LFV ?)						
Extensive energy variability	F_L						
Higher-precision detector(s) ?							
Forward/backward detectors	Diffraction Low t processes						

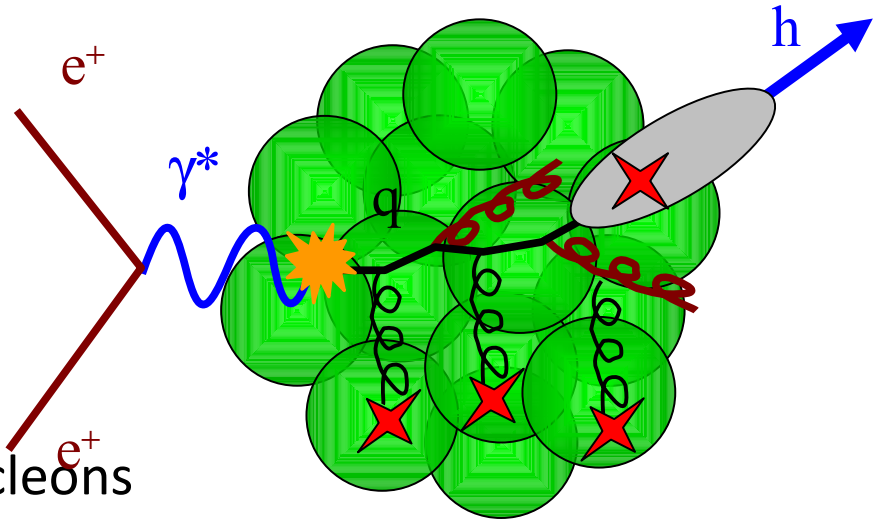
Golden measurement candidates

- F_2 , F_L , F_2^c with equal (HERA-level) precision
- Inclusive diffraction
  (unique suppression/enhancement patterns)
- Dihadron (dijet) azimuthal decorrelation
- Diffractive J/Psi, DVCS,
  (coherent AND incoherent parts)
- Jets and Hadronization

Parton propagation and fragmentation

Review: Accardi et al., Riv.Nuovo Cim.032,2010

- **Nuclei as space-time analyzers**



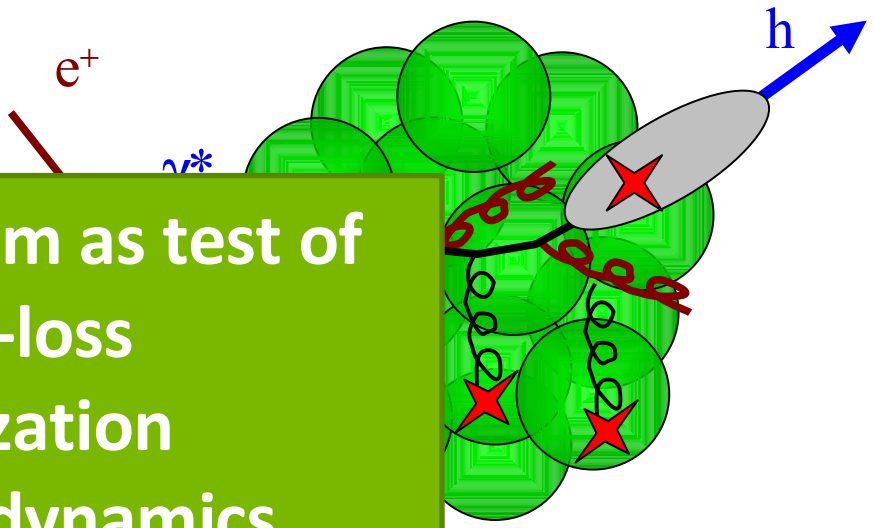
- **Non perturbative aspects**
  - Color confinement dynamics
  - Probe nuclear gluons
  - new look at TMDs in “bound” nucleons
  - novel access to gluon GPDs
  - transport coefficients qhat, ehat

- **Perturbative QCD**
  - testing pQCD energy loss
  - DGLAP evolution, parton showers, jets

Parton propagation and fragmentation

Review: Accardi et al., Riv.Nuovo Cim.032,2010

- **Nuclei as space-time analyzers**



- **Non perturba**
  - Color con
  - Probe nuc
  - new look
  - novel acc
  - transport

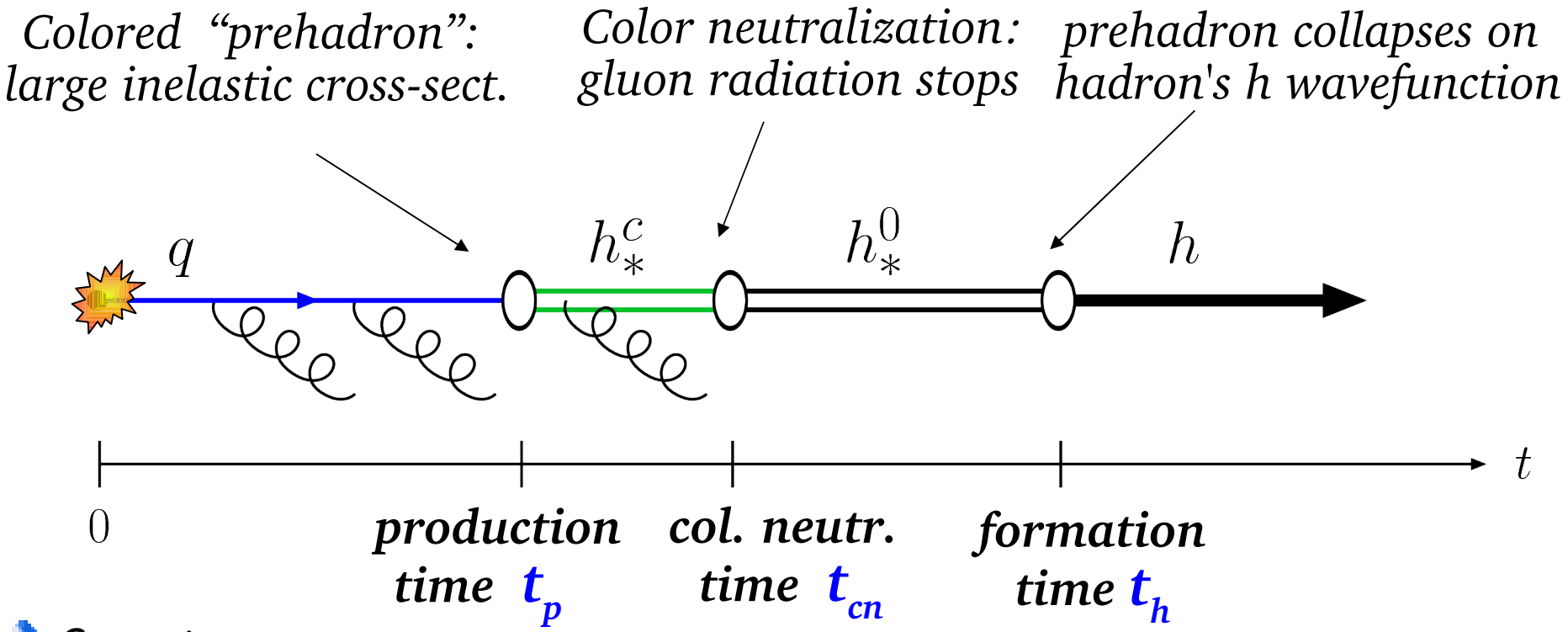
Using the medium as test of
- energy-loss
- hadronization
- jet shower dynamics

Using the jet shower (hadrons)
as probe of the cold medium

- **Perturbative**
  - testing pQCD energy loss
  - DGLAP evolution, parton showers, jets

The (naïve) framework : quark, prehadron, hadron

- Hadronization is non perturbative $\Rightarrow$ (many) models
- General features:

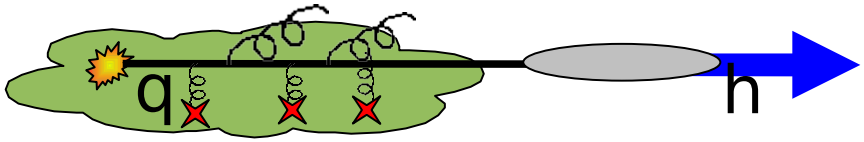


- *Caveats:*
  - It's tricky to define t_p, t_{cn}, t_h: working tools – simplify: $t_p = t_{cn}$
  - Leading-order pQCD mindset (γ^*+q -> q), but NLO may be large

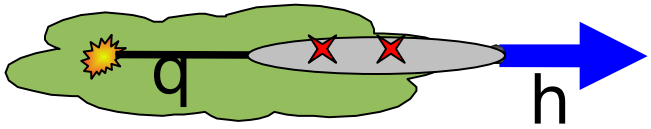
Hadron attenuation in nDIS

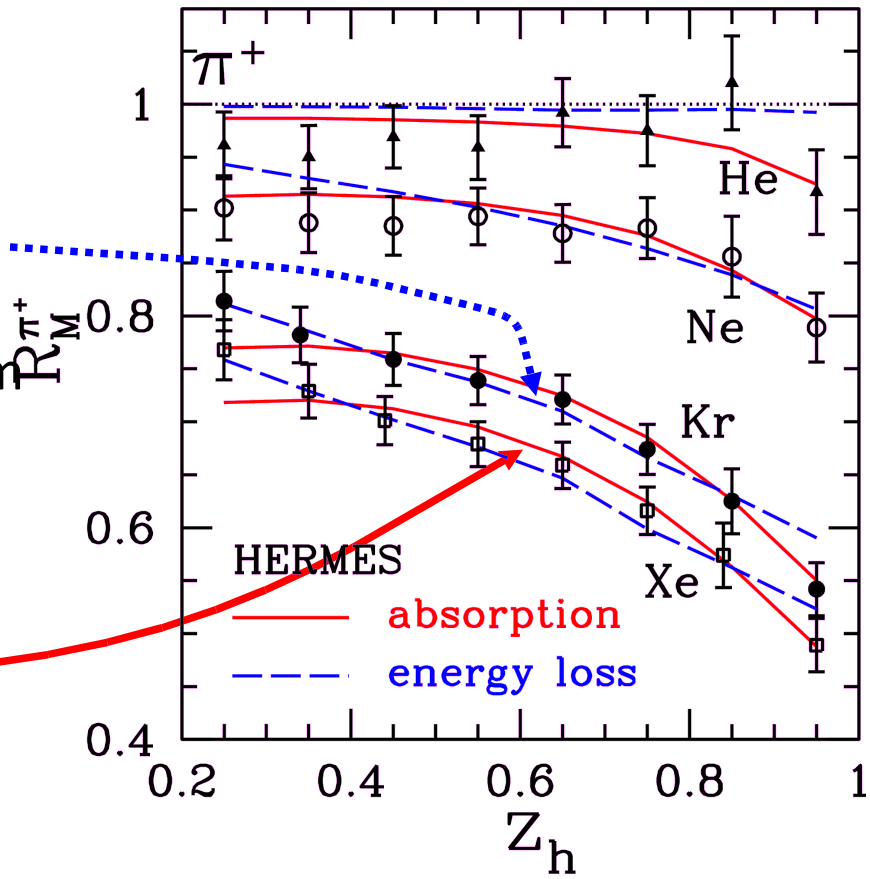
$$R_M^h(z) = \frac{\frac{1}{N_A^{\rm DIS}}\frac{dN_A^h(z)}{dz}}{\frac{1}{N_D^{\rm DIS}}\frac{dN_D^h(z)}{dz}}$$

- **Energy loss (gluon bremsstrahlung)**
  [Arleo; Wang *et al.*; Accardi]
  - hadronization outside the medium
  - gluon radiation off struck quark



- **Prehadron absorption**
  [Accardi *et al.*;
  Falter *et al.*; Kopeliovich, *et al.*]
  - color neutralization inside the medium
  - prehadron-nucleon scatterings





[A.A., et al., NPA 761(05)67]

[A.A., Acta.Phys.Hung. '06 & PRC '07]

Gold with jets and hadrons

Need to summarize and make crisp claims,
prioritize detector requirements,
determine luminosity requirements

- Summary plots with computations in different approaches ????
  - what is the sensitivity of a given observable to different models?

Theory curves

- Accardi, Dupre, Kopeliovich, Gallmeister, Majumder
- ...

What are the <u>most</u> interesting observables?
(we can only highlight a few as "golden")

Gold with hadrons

Hadrons

- RM(z) in fixed nu bins, up to large nu / RM(pT) fixed z, nu bins
- pT-broadening (also, connection with Qsat)
    - pion vs. K+ vs. K-
    - pi, eta / K, phi, ...
    - baryons: p, Lambda, ...
- dihadron acoplanarity vs A, etc...
- light vs heavy
- HEAVY: bottom should be substantially different than charm
    - smaller RM because of more absorption??
    - pT-broadening: the partonic phase maybe very short

- J/psi
    - photo-production -> enhancement (Kopeliovich)
    - J/psi absorption mechanism
    - ...

- psi', upsilon, ...

Gold with jets

Nucleus as probe of jet showers ?

- imagine qhat, ehat determined by RM vs pT-broad vs. ... with hadrons
- can use cold nucleus to probe the space-time evolution of the jet shower
    - accessible in pQCD (Sterman, INT 2009)
    - kT vs angular ordering ?
- many more variables, more handles on energy loss / transport coeff. themselves

Jets as probe of cold matter?

Crucially: WHAT JETS OBSERVABLES?

- RM(jets) vs. cone radius?
- jet shapes?
    - which one are most promising?
    - need sensitivity to transverse and/or longitudinal energy flow
- c-, b-tagged jets: (very) different from light jets